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SAFETY RESEARCH OF INSULATING MATERIALS OF CABLE FOR NUCLEAR POWER GENERATING STATION

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INTRODUCTION

To the Honorable Chief of the Korea Energy Research Institute

This report is offered as the research report for 1981.

Subject Title: Research on the Safety Properties of the Insulating Materials on the Electrical Cables Used in Nuclear Generating Stations

January 1982

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SUMMARY

The polymers PE, EPR, PVC, Neoprene, CSP, CLPE, EP, and other similar substances are frequently being used as insulation and covering materials for cables used in nuclear generating stations. Giving consideration to the required information for these cables for flame retardancy and environmental resistance tests as well as to the experimental methods and cable specifications, through the cable normal test, flame test, chemical tests, design basis event and loss-of-coolant accident tests plusbasic material collected concerning the spark tests and actual experience, standards were fixed through these contributions and technology was accumulated.

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I. Conclusions and Suggested Items 5

1. Conclusions

Although polymer polyethylene (PE), ethylene propylene rubber (EPR), polyvinylchloride (PVC), neoprene, chlorosulphanated polyethylene, CSP (hyparon), chlorinated polyethylene (CLPE), ethylene propylene (EP), and other similar substances are much used as PWR cable materials. At the present time, in the cables being used in the old style nuclear generating stations, EP, EPR, Neoprene, CSP, and CLPE are mainly being used as insulating materials and coverings.

With the cables installed in nuclear generating stations as focus, consideration was given to such things as information required concerning the flame retardancy and environmental resistance of cables, test methods, and the specifications of cables. As far as such things as the information required concerning cable safety, and test methods were concerned, the U.S. standards were taken as the basis. It is still true that in our country, research concerning these matters is still not being done. Consequently, this year, for the first time, through experimentation and the collection of basic materials concerning the spark or flame test among i) the normal test ii) the flame test iii) the chemical test, and iv) the DBE (Design Basis Event) as well as the LOCA (Loss-of-coolant accident) test, Korean standards were set from these contributions and the associated techniques were accumulated. Along with this, in order to carry out parallel tests for material changes in cables, although partial tests were carried out on the nature of the materials in the cables, there are still points that have not been decided.

When doing tests to evaluate the safety characteristics of cables, the reference materials that were helpful were primarily IEEE 383, 323, IPCEA S-68-516, IPCEA S-19-81, ASTM D 2863, ASTM D 2671, 6
IPCEA S-61-402 and JIS, JCS specifications, as well as other similar references.

2. Suggested Items

As a problem which we have just begun to deal with this year and in which there is insufficient basic information concerning a field of specialization in which there is work to be done, there have been many roadblocks. However, in line with the future trends, research into the safety characteristics of cables is thought to be necessary.

II. Preface

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As concerns the cables that are used in the radiation line installations for such things as nuclear reactors, much use is made of high polymer materials in the electrical lines and instruments (1-3). In cases where the covering materials for these are irradiated with large amounts of radiation, problems such as heating and the radiation resistance characteristics (5), flame retardance (9-10), heat resistance (11,12) and similar problems associated with high polymer materials as they occur in the mechanical properties (4) arising from the going bad of covering materials come to the fore very clearly. Because of this, as far as the cables which are currently being used in nuclear reactors are concerned, standards concerning product quality recognition have been set, and, in line with this, the object of these tests has been to make the production of adequate cables possible.

As far as product quality recognition for the IE class cables currently in use in nuclear generating stations at the present time is concerned, the U.S., West Germany, France, Japan, and other similar countries among all the advanced nations have established standards or are developing new cables for use in nuclear generating stations. In particular, as important information (3) basic to the subject of cables, the important subjects of flame retardance (14,15) and environmental resistance (16,17) are being discussed and researched. As concerns these important matters, as the years have gone on, they have become more and more demanding, and the test methods for deciding whether or not cables were appropriate have been getting even more strict. Moreover, getting in step with these kinds of trends, the the realization of basic research and the development of new manufacturing technologies as well are being carried forward, and, in order to guarantee functional capabilities, quality control systems are also even more firmly being put in place.

Focusing on the cables which are actually installed in generating stations, as far as the flame retardance characteristics and environmental resistance of the cables are concerned, if one wishes to summarize them, the PWR type or the BWR type nuclear generating station have cables installed in them for which the important informational items are the test methods, the cable specifications,and

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other similar items. As far as concerns this type of recognition test content, besides cables, when setting up recognition tests for instruments that are used in nuclear generating stations, these items are also considered to be helpful. By the application of the flammability characteristics of cables used in nuclear generating stations, there can be made a general type of flame resistant cable, and, in factories and thermal powered generating stations as well, these flame resistant cables will be necessary. In cables used in nuclear generating stations, accumulated testing techniques or manufacturing technology becomes the mother load, exerting an influence on the manufacturing world as well.

The flame retardant properties of cable materials and insulation materials involve the use of various types of high polymers. Fluorocarbons, polyvinylchloride (PVC), or neoprene and high polymers in which halocanes are combined on the backbones of such substances make additive substances almost unnecessary. In the case of systems with reverse side polyolefins, in order to obtain adequate flame retardance characteristics, such materials as halocane and antimony oxide are necessary. Among compounds formed with halocane, compounds containing bromine are generally more effective. The most widely used materials supplying insulating properties and flame retardance include PVC, chloridized PE, operene, polyolefin, fluoridized carbon compounds, silicon compounds, EPR (ethylene propylene rubber), and other similar compounds.

The nuclear generating stations which are attracting interest, in our country as well, by approximately the year 2000 will be more than 30 in number, and, since it is projected to construct these nuclear reactors to be used in the production of electricity, the safety characteristics of these installations are emerging as a serious question without any doubt. Because of this, the safety characteristics of the cables installed inside nuclear generating stations are occupying another important place, and, because of this, it is thought that, before the fact, recognition or certification testing methods concerning the safety characteristics of these cables must be set up as a basis along with the necessary materials (18-22) on the specifications of cable standards.

In this research study, as concerns the first year's nuclear generating stations and the flame tests on the cables used in them as well as their certification test methods and their cable specifications, the necessary information is set out.

1. Specifications Used in Light Water Reactors

A. Cable Covering Material Characteristics

Representative cable covering materials include such substances as polyethylene, polyvinylchloride, ethylene propylene rubber (EPR), silicon rubber, chloroprane rubber, chlorosulfanated polyethylene (hyparon), and other similar substances. As far as the acid component indices of these covering materials are concerned, they are as shown in Table 1, and comparisons can be carried out with the degree of combustibility. The cable insulation properties, their environmental resistance, their flame retardance characteristics, their resistance to heat, and their mechanical characteristics (compare Table 2) and other similar factors are considered, and an overall decision is made, selecting the most appropriate material for design and manufacture.

1) Polyethylene (PE), and Polymer Polyethylene

The electrical characteristics of PE are excellent, and it is an insulating material with many types of uses. Also, it has relatively good resistance to radiation rays or lines. Generally speaking, in electrical cables, polymer PE is being used. In the case of polymer PE, as regards heat resistance, it increases, but there is no big change in resistance to radiation. As concerns the flammability characteristics possessed by flame retardant polymer PE, in an appropriate combination (copy unclear) it is possible to maintain radiation resistance characteristics similar to those for polymer PE, and it is used as insulating material for the cable used in nuclear electrical generating stations.

(1) 표 1. 케이블 피복재료의 산소지수 [5]

(2) 피 복 재 료	(3) 산소지수
(4) 폴리에틸렌 (PE)	19
(5) 가교 PE	19
(6) 난연 가교 PE	27
(7) 비닐	34
(8) 난연 저압신 비닐	30
(9) 특수내열 비닐	36.5
(10) 난연 저압산 특수내열 비닐	30
(11) 폴리염화프로필렌 고무 (CR 고무)	19
(12) 난연 EP 고무	27
(13) 난연 실리콘 고무	33
(14) 난연 프로폴프렌	33
(15) 난연 하이파론	33

1. Table 1 Oxy. Component Indices for Cable Covering Materials 5)
2. Covering Materials 3. Oxy. Component Indices 4. Polyethylene (PE)
5. Polymer PE 6. Flame Resistant Polymer PE 7. Vinyl 8. Flame Resistant Low Hydrochloric Acid Vinyl 9. Special Heat Resistant Vinyl
10. Flame Retardant Low Hydrochloric Acid Special Heat Resistant Vinyl 11. Ethylene Propylene Rubber (EP) Rubber 12. Flame Resistant EP Rubber 13. Flame Retardant Silicon Rubber 14. Flame Retardant Propylene 15. Flame Retardant Hyparon

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(1)표 2. 케이블 구성재료의 기계적 특성 (절연재료 규격치)[10]

(2)재 료 / 특 성 (3)	(4)난연성 EPR	EPR	난연성가교 (5)	가교 PE (6)	PVC (7)(폴리비닐클로라이드)	특수내열 PVC (8)
인장강도 (9)(Kg/mm^2)	0.4이상(14)	0.4이상(14)	1.0이상(14)	1.0이상(14)	1.0이상(14)	1.5이상(14)
신장 (%) (10)	300이상(14)	300이상(14)	350이상(14)	350이상(14)	120이상(14)	150이상(14)
열노화 특성 (11)	(100±2°C 168일)(15)	(100±2°C 168일)(15)	(120±2°C 168일)(15)	(120±2°C 168일)(15)	(100±2°C 72일)(15)	(120±2°C 168일)(15)
인장강도 잔율 (%) (12)	80이상(14)	80이상(14)	80이상(14)	80이상(14)	85이상(14)	90이상(14)
신장 잔율 (%) (13)	80이상(14)	80이상(14)	80이상(14)	80이상(14)	80이상(14)	85이상(14)

1. Table 2 The Mechanical Characteristics of Constituent Materials of Cables (Specification Sheet for Insulation Materials) (10) 2. Material 3. Characteristic 4. Flame Retardant EPR 5. Flame Retardant Polymer 6. Polymer PE 7. PVC (Polyvinylchloride) 7. Special Heat Resistant PVC 9. Drawing Strength (Kg/sq. mm) 10. Extension (%) 11. Heat Aging Characteristics 12. Drawing Strength Retention Rate (%) 13. Extension Retention Rate (%) 14. Above 15. Day

2) Polyvinylchloride (PVC)

PVC has excellent processing characteristics and flame retardance, and, in the cables used in nuclear electrical generating stations, special flame retardant agents are added to it to make its flame retardance even higher. Not only is that true, but, in order to reduce the production of hydrogen chloride (HCl) at times when fires do occur, appropriate agents are also specially supplied. The radiation resistant characteristics of PVC cannot be considered good, and they begin to deteriorate from 50-100 Mrad on. 12

3) Ethylene Propylene Rubber (EPR)

The heat resistance and special characteristics of EPR are not only those of a wonderful new material. Its radiation resistance characteristics are also at a good level similar to that of polymer PE. Because this is so, EPR. with its flame retardance characteristics, is being used as insulation material on cables in nuclear powered electrical generating stations. On the cables of nuclear electrical generating stations in Korea, large amounts of EPR are in use.

4) Silicon Rubber

In the case of silicon rubber, particularly under high temperature conditions, it is a material with excellent heat resistance properties. Even though it is in use in nuclear electric generating stations, as a cable covering material, its mechanical properties are somewhat unsatisfactory, and it is strengthened with substances like glass. Its radiation characteristics are not good, but, even after deterioration due to radiation, its electrical insulation properties are not particularly reduced, which is a special feature.

5) Chloroprene Rubber

Chloroprene rubber, as a rubber with good flame retardance characteristics, is a material much used as a sheath on cables. However, because its radiation resistance properties are not good, it begins to harden when exposed to radiation of the 50 Mrad level.

6) Chlorosulfanated Polyethylene (Hyparon)

In the case of hyparon, its flame retardant characteristics and heat resistance are excellent, and it is used mainly as a sheath. Not 13

only that but, since its radiation resistance characteristics are excellent, it is used as a sheath material for the cables used in nuclear powered generating stations. However, this material is relatively expensive, so its price is considered a draw back.

b. Specifications for PWR Use Cable

As far as the specifications for the PWR use cable which has been much used lately are concerned, they can be roughly divided into high voltage electric cable, low voltage electric cable, and control cable, and these categories appear in Table 3. Under environmental conditions of 2×10^8 rad gamma radiation or simulated LOCA loads, the cables in the safety protective circuits inside the C/V make use of flame retardant EPR as insulating material, and, as the sheath material for the cables used in the safety protective circuits, a non-organic woven material of asbestos is used. Besides this, flame retardant substances are made use of in the materials. However, their use creates problems, and, at the present time, they are not being used. The difference between lines 1 and 2 in Table 3 is the insulation materials used on the low voltage electrical cables and the control cables of the C/V exterior safety circuits and the non-safety circuits inside the C/V. In the case of Line 1, it represents flame retardant EPR, and Line 2 is special heat resistant PVC. Consequently, as concerns such problems as radiation resistance characteristics, the production of noxious gases during times of fire, and so on, the flame retardant EPR has the advantage, but, from the economic point of view, the special heat resistant PVC is thought to have the advantage.

(1)표 3. PWR용 케이블의 시방 (Specification)[19]

	케이블 용도(2)		(3) 케이블 시방 (예 1)		(4) 케이블 시방 (예 2)	
	(5) 구분	(6) 장소	(7) 절연체	쉬이쓰 (sheath)	(8) 절연체	쉬이쓰 (sheath)
고압케이블(9)	안전회로(10)	C/V내(11)	가교 PE (20)	난연특수내열 PVC(23)	가교 PE(20)	난연특수내열(23) PVC
	비안전	C/V내(11)	가교 PE (20)	난연특수내열 PVC(23)	가교 PE(20)	난연특수내열(23) PVC
	회로(13)	C/V외(12)	가교 PE (20)	난연(21) PVC	가교(20) PE	난연(21) PVC
저압케이블(14)	안전	C/V내(11)	난연 EPR (21)	난연 하이푸론(24)	난연 EPR(24)	난연 하이푸론(24)
	회로(15)	C/V외(12)	난연 EPR (21)	난연특수내열 PVC(23)	특수내열 PVC(22)	난연특수내열(23) PVC
	비안전	C/V내(11)	난연 EPR (21)	난연특수내열 PVC(23)	특수내열 PVC(22)	난연특수내열(23) PVC
	회로(16)	C/V외(12)	특수내열 PVC(22)	난연 PVC(21)	특수내열 PVC(22)	난연(21) PVC
제어케이블(17)	안전	C/V내(11)	난연 EPR (21)	난연 하이푸론(24)	난연 EPR(24)	난연 하이푸론(24)
	회로(18)	C/V외(12)	난연 EPR (21)	난연특수내열 PVC(23)	특수내열(22) PVC	난연특수내열(23) PVC
	비안전	C/V내(11)	난연 EPR (21)	난연특수내열 PVC(23)	특수내열(22) PVC	난연특수내열(23) PVC
	회로(19)	C/V외(12)	PVC	난연 PVC (21)	PVC	난연(21) PVC

1. Table 3 PWR Use Cable Specifications 11) 2. Cable Use 3. Cable Specifications (Case 1) 4. Cable Specifications (Case 2) 5. Specification 6. Site 7. Insulation Material 8. Insulation Material 9. High Voltage Cable 10. Safety Circuit 11. Inside 12. Outside 13. Non-Safety Circuits 14. Low Voltage Cable 15. Safety Circuits 16. Non-Safety Circuits 17. Control Cables 18. Safety Circuits 19. Non-Safety Circuits 20. Polymer 21. Flame Retardant 22. Special Heat Resistance 23. Flame Retardant Special Heat Resistant 24. Flame Retardant Hyparon

As far as low voltage cables or control cables are concerned, heat resistant materials are being used as insulators, but, by comparison, in the case of high voltage cables, more attention is given to electrical characteristics and, normally, polymer PE is used as insulation material. 15

Besides electrical cables and control cables, the cables connecting to the electrical computers and calculating devices inside of generating plants involve the use of a large amount of electrical line. As far as these electrical lines are concerned, as their sheath materials or insulators, silicon rubber or PVC is being used, but, it is to be hoped that the same thought is being given to the specifications established as a basis for these lines as is given to those for electrical and control cables.

c. BWR Cable Specifications

A case concerning the specifications for BWR use cables is given in Table 4. As far as the cable used inside and outside the PCV is concerned, all of them, because they are required to pass a simulated LOCA test in a high temperature and high pressure steam atmosphere, use, as insulating materials, polymer PE, silicon rubber, EPR and other similar methyl sulfonate polymer materials. Among these, in high temperature realms, silicon rubber and insulating glass substances are being used. As far as sheathed cable is concerned, it must satisfy the environmental conditions for the interior of the PCV. As concerns high voltage cables, they are of a PWR type, and, in terms of insulation material, they are not flame retardant.

(1) 표 4. BWR 용 케이블의 시방[18]

(2) 케이블 종류	장소(3)	(4) 케이블 시방	
		절연(5) 재	쉬스(6) 이 쓰
(7) 고압전력 케이블	PCV(11) 외	가교(14) PE	난연(17) PVC
	PCV(12) 내	EPR	난연(18) 클로로프렌
(8) 저압전력 케이블	PCV(11) 외	난연가교(15) PE	난연(17) PVC
(9) 제어계장 케이블	고습(13) 장소	실리콘(16) 고무	유리(19) 섬유
(10) 보상도선	PCV(12) 내	난연(17) EPR	난연(18) 클로로프렌

1. Table 4 BWR Use Cable Specifications 18) 2. Cable Type 3. Site 4. Cable Specification 5. Insulation Material 6. Sheath 7. High Voltage Cable 8. Low Voltage Cable 9. Control Conversion Cable 10. Compensating Wiring 11. Outside 12. Inside 13. High Moisture Environnment 14. Polymer 15. Flame Retardant Polymer 16. Silicon Rubber 17. Flame Retardant 18. Flame Retardant Chloroprene 19. Glass Materials

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2. Required Information and Test Methods Concerning Cables 17

a. Required information concerning cables

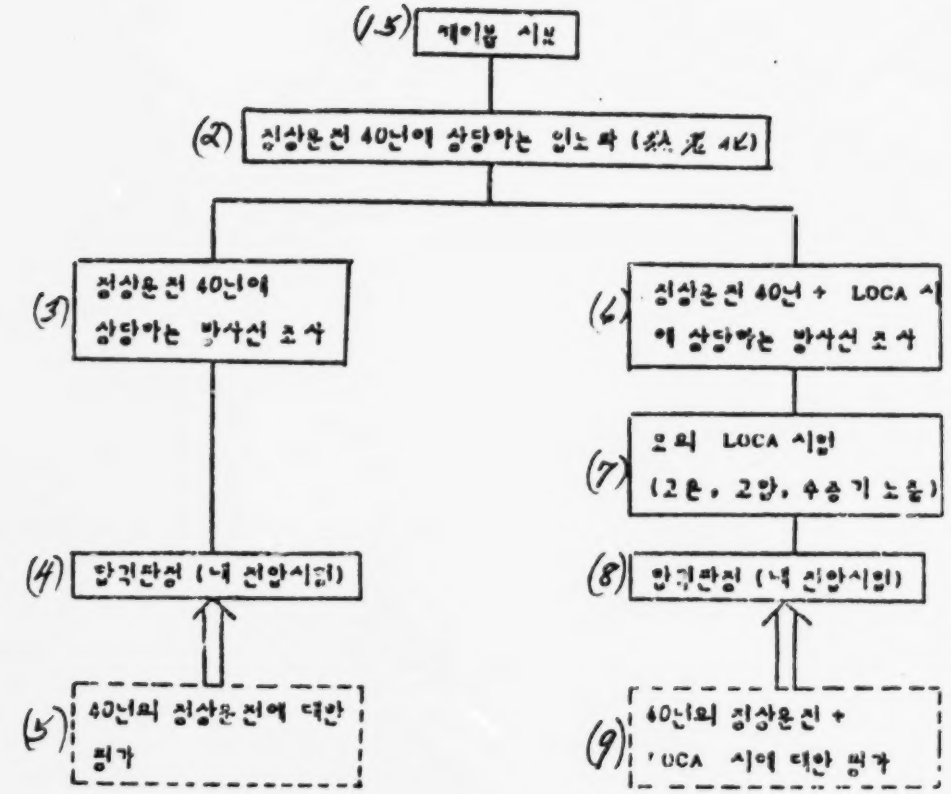
As concerns the information required on cables, it is mainly based on the IEEE Standard from the U.S., and these are generally divided into environmental tests (Fig. 1, Fig. 2, Table 5, Table 6 are references) and combustion tests (Table 7).

As far as the cables which are being used in nuclear generating stations are concerned, at the same time that they satisfy the normal specifications established by the IEEE Standard, the IPCEA regulations and other usual specifications, they also satisfy the following types of items. i) They must be able to stand up to the heat and radiation received in 40 years of normal operation. ii) When loss of coolant accidents occur (LOCA) in the Design Basis Events or DBE), they must fulfill their functions as cables in this environment. iii) In the case where there is a fire in the DBE, the cables must not spread the flames. Also, when the cables are burning, the production of noxious gases and smoke, in particular, must be reduced.

In the case of cables being used as IE class cables in nuclear generating stations, PWR safety protective systems, and BWR emergency reactor core cooling systems the conditions in i) ii) and iii) are required, and, in other cables, conditions i) and iii) must be satisfied.

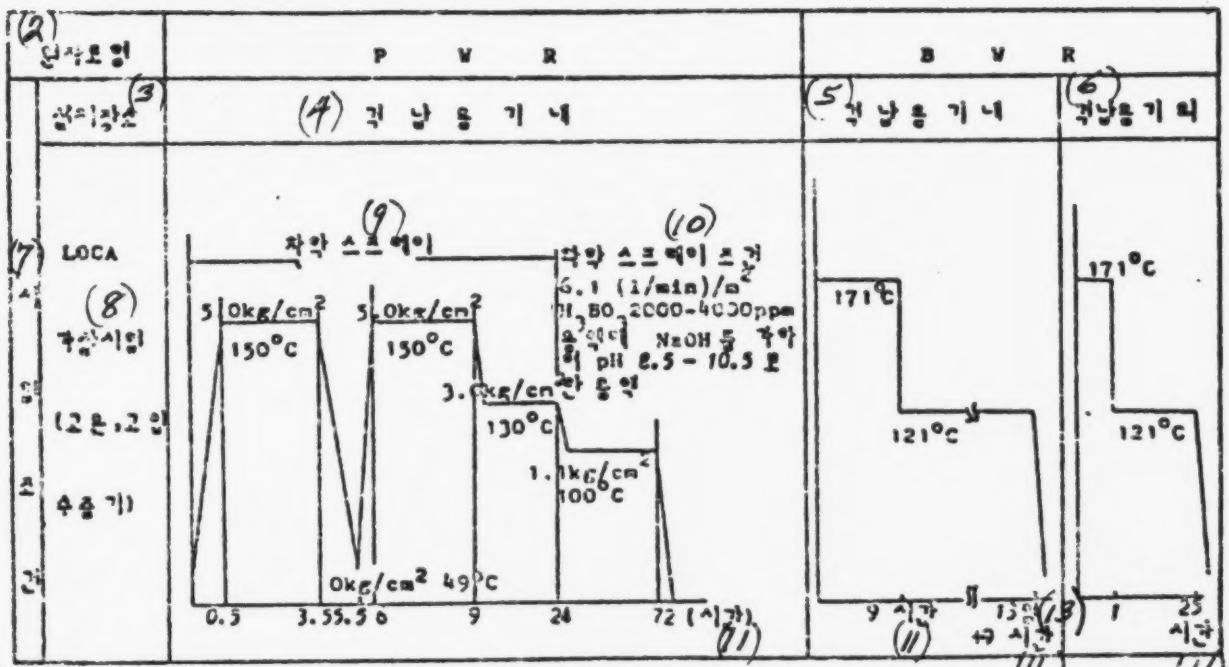
b. Test methods relating to cables

As far as 8,000 volt standard power cable is concerned, there are Deleted type and Triplexed type. Generally speaking, there are three types of tests that are carried out: i) Normal Testing 19), ii) Flame Testing 19), and Chemical Testing 19). However, in the case of 600 volt control cable 21), along with the three types of tests which are carried out on power cables, a fourth, iv) Design Basis Event and Loss of Coolant Accident test must be included. (This is the case with the Kori nuclear powered generating station). 23



(1) 그림 1. 환경시험 순서[8]

1. Fig. 1 Environmental Testing Sequence (8) 1.5. Cable Specifications (copy unclear) 2. Heat Aging Equivalent to 40 years of normal operation 3. Radiation exposure equivalent to 40 years of normal operation 4. Pass determination (interior voltage test) 5. Evaluation of 40 years of normal operation 6. Radiation exposure equivalent to 40 years of normal operation + LOCA conditions 7. Simulated LOCA Test (high temperature, high voltage, exposure to steam) 8. Pass determination (interior voltage test) 9. Evaluation of a LOCA situation + 40 years of normal operation



(1) 그림 2. LOCA 구상시험 조건[17]

1. Fig. 2 Simulate LOCA Condition Test (2) (copy unclear) 2. Form of Basic Materials 3. Set Up Site 4. Containment Vessel Interior 5. Containment Vessel Interior 6. Containment Vessel Exterior 7. Test Conditions 8. Simulated LOCA Test (high temperature, high voltage, steam) 9. Chemical Spray 10. Chemical Spray Conditions Formed by Adding to a Reagent of 6.1 (l/min)/m² H_3BO_3 2000-4000ppm a Reagent Formed by Adding NaOH at pH 8.5-10.5 11.5 11. Hour 12. Note: During the hypothetical LOCA test, the tests determining compliance with regulations and the spreading tests are conducted. (Copy unclear). 13. Day

(1)표 5. 케이블의 환경조건[8]

(2)형 식		P W R				B W R	
(3)설치장소		격납용기(C/V) 내 (4)	C/V 내 (5)	C/V 외 (6)	C/V 외 (6)	C/V 내 (5)	C/V 외 (6)
회로(7)구분		(8)안전보호회로	(9)비안전보호회로	안전보호회로 (8)	비안전보호회로 (9)	-	-
(10)시험조건	(11)열 노 화	121°C × 7일(12) 140°C × 9일(12) 150°C × 15일(12)	121°C × 7일(12) 140°C × 9일(12) 150°C × 15일(12)	121°C × 7일(12) 140°C × 9일(12) 150°C × 15일(12)	121°C × 7일(12) 140°C × 9일(12) 150°C × 15일(12)	121°C × 7일 (12)	121°C × 7일 (12)
	방사선조사 (13) 정상운전 40년(14)	5×10^7 rad	5×10^7 rad	5×10^7 rad	1×10^6 rad	5×10^7 rad	3×10^7 rad
	방사선조사 (13) LOCA시(15)	1.5×10^8 rad	-	-	-	2.6×10^7 rad	-

1. Fig. 5 Cable Environmental Conditions 2. Form of the Basic Materials 3. Set Up Site 4. Containment Vessel (C/V) Interior 5. Interior 6. Exterior 7. Circuit Specification 8. Safety Protective Circuit 9. Non-Safety Protective Circuit 10. Test Conditions 11. Heat Damage 12. Day 13 Gamma Ray Radiation 14. 40 Years of Normal Operation 15. At the Time of LOCA

(1)도 6. LOCA 구상시험 (PWR 용)[23]

600 Volt Control Cable-EPR Insulation and Neoprene or CSP Jacket.

시 (2) 간	(3) 온도 °F	스팀압력 lb/in²g (kg/cm² gage) (4)	화학스프레이 (5) 참고 1*	(6) 전 압 (60Hz)	(7) 전 류 (amp)
1) 0 초 (8)	300	55 (3879.28)		480	6
2) 1분 (9)	340	70 (4923.20)		480	6
3) 다음 5시간 (10)	340	70 (4923.20)		480	6
4) 다음 1시간 (10)	320	70 (4923.20)		480	6
5) 다음 18시간 (10)	300	55 (3879.28)		480	6
6) 다음 1일 (11)	250	15 (1046.40)		480	6
7) 30일 (11)	200	0 (0)		480	6

(12) 참고 1* : 340°F 에 도달한 후 1분 내에 시작하여 NaOH 로 완충된 붕산용액이 전시간에 0.15gal/min/ft² 의 속도로 연속적으로 시료 케이블에 스프레이 된다.

(13) 참고 (1) : 600 Volt 제어케이블 - CLPE 절연재와 CLPE 피복재의 경우 위와 같으나 전류가 1 amp 인 것만 다르다.

(2) : 600 Volt Instrument Cable-EPR 절연재 Neoprene 또는 CSP 피복재 경우도 위와 같으나 전류가 1 amp 인 것만이 다르다.

1. Fig. 6 Simulated LOCA Tests (on PWR) 12) (copy unclear) 2. Duration 3. Temperature 4. Steam Pressure 5. Chemical Spray Note 1 6. Voltage 7. Current 8. Second 9. Minute 10. Hour 11. Day 12. Note 1: After reaching 340 degrees Fahrenheit, during one minute, one begins to spray a solution of boracic acid fully loaded with NaOH into the whole area at a continuous speed of 0.15 gal/min/sq. ft. (copy unclear) 13. Note (1): 600 volt control cable - CLPE insulation material and CLPE covering materials, when used as comparison cases, produced only a 1 amp current difference when compared to the above. (2) 600 Volt Instrument Cable- EPR insulation and Neoprene or CSP covering materials, when compared with the above, showed only a 1 amp current difference.

(1) 표 7. 연소시험 항목[8]

(2) 시험방법	(3) 시료	(4) 평가기준	(5) 규격
(6) 수직트레이 연소시험	(7) 케이블 완성품	(8) 케이블 시료 상단까지 연소(延燒)하지 말것	IEEE Std. 383, 2.5항 (9)
(10) 선심수직 연소시험	(11) 절연선심	(12) 그라프트지가 25% 이상 손상되지 말것 시료가 1분이상 연소를 지속되지 말것	IPCEA S-19-81 6, 19, 6항 (13)
(14) 산소지수 시험	(15) 케이블 구성재료	(16) 절연체 25 이상 쉬이스 27 이상	JIS K7201
(17) 염화수소가스 발생시험	(18) 쉬이스재료	(19) 100mg/g 이하 (고압케이블 경우 150mg/g 이하)	JCS C5302 (20)

1. Fig. 7. Combustion Test Items (9) (copy unclear) 2. Test Method 3. Test Material 4. Evaluation Standard 5. Regulation 6. Vertical Tray Combustion Test 7. Finished Cable Constituents 8. Not Burning to the Top Edge of the Cable Test Material 9. Article 10. Line Core Vertical Combustion Test 11. Insulation Line Core 12. The Wrapper Paper Not More Than 25% Damaged. Test Material Does Not Continue to Burn for More than .1 (copy unclear) Minute 13. Article 14. Acid or Oxygen Index Testing 15. Cable Constituent Materials 16. Insulating Materials 25 and Up Sheath 27 and Up 17. HCl Gas Production Test 18. Sheath Material 19. 100mg/g or less (in the case of high voltage cable, 150mg/g or less) 20. No.

1) Normal Tests

As far as normal testing is concerned, there are three types of tests; that is, (a) the Electrical Test, (b) the Test on Samples, and (c) Aging and Radiation Exposure Tests.

a. Electrical Test

As concerns the Electrical Test, there are four types of tests involved; that is, AC electrical tests, insulation tests, DC electrical tests, and electrical conductor resistance tests. In the case of the AC electrical tests, insulation tests, and DC electrical tests, IPCEA S-68-516 must be followed, and, in the case of the electrical conductor resistance tests, IPCEA S-19-81 must be thoroughly applied. It is hoped that references 19-22 will be consulted.

b. Test on Samples

As far as the testing process is concerned, IPCEA S-19-81, Section 6.2-6.21 must be thoroughly observed, and, as concerns the tests run on the test materials, they must include, at a minimum, the four types which follow. (1) Measurements of cable diameter with respect to unit surface areas of conducting bodies (2) Measurements of semiconductor types and metallic types (3) Measurements of insulators and covering materials, and (4) Physical tests and deterioration tests on insulation and covering materials.

c. Heat Aging and Radiation Exposure Tests

As far as the tests below are concerned, the requirements of IEEE 383 and 323 must be satisfied. (1) Thermal Aging Test 24

As concerns test materials from the cables, assuming a 40 year life for the cables, we heat aged them at 302 degrees F. (105 deg. C) for 7 days in an air oven. The permissible values used in these thermal or heat tests for test times and parameters are as shown in Table 8 which follows.

(2) Radiation Exposure Test

As far as the test materials are concerned, we assumed a 40 year radiation exposure, and, from a (^{60}Co) radiation source, exposed them to a 0.1×10^{8} rad amount of gamma radiation. As concerns the irradiated test materials, mechanical certification and electrical certification tests had to be done, and, at 77 degrees F. (25 deg. C), by wrapping them around a mandrel periphery, one piece each had to satisfy the bending requirements of IPCEA S-19-81,

Sections 6, 10, and 3. As far as the test samples are concerned, it was necessary to do the DC high voltage test for a minimum of 5 minutes with the 240 Volts/mil(220/0.025mm) insulation of IEEE 383 (number unclear). Adding these insulation characteristics to the bending and electrical test results, they are as presented in Table 8. As far as the matters mentioned above are concerned, it is hoped that the reader will consult references 19-22.

2) Flame Test (1,5,21)

As far as insulation materials and covering materials are concerned, their non-flammability and flame retardance as materials were tested on the basis of IEEE 383 Section 2.5, and, depending on the uses to which they were put, their acceptable values were somewhat different. As concerns the test materials used in the flame tests, they had to be supply cable in use, and, as far as the testing methods are concerned, flame from the gas burner flame source method was used. (See Fig. 3 and 4).

(1) As far as the test materials are concerned, 6 foot (1.8m) lengths of Triplex-4/0 AWG cable were set up vertically in several separate strips. 29

(2) As concerns the cable, without a cover, plated steel, in a ladder-type cable tray, held the pieces half a cable diameter apart set up in rows 6 inches (1.5cm) from each other. As far as the tray is concerned, it had a height of 8 ft. (2.4m) and a depth of 3 inches (7.6cm). Its width had to be 12 inches (30.5cm). As concerns the cable, it was fixed in the trays by plastic cable attachments hanging from above and below the trays. As far as the metal fasteners or attachments are concerned, they were there to keep the cables riding in the trays from falling out and were made use of in the top sections.

(3) On the basis of a three line supply of neutral single phase 240-(220-) volt AC, three test cables were each monitored for circuit continuity.

(4) As far as the tests are concerned, they were carried out in a room without ventilation or in a sealed space supplied with an appropriate amount of air.

(5) As concerns gas burners, an American Gas Furnace Company, 10 inch (22.4cm) width, 11-55 drilling, ribbon type Catalog No. 10x11-55 attached to an air-gas venturi mixer, catalog No. 14-18 [21b/in.g(139.53g/sq.cm gage) maximum pressure] was used. As concerns burners, if installed horizontally, the flames reached the test samples between the rungs of the trays, and, as far as the burners are concerned, they were positioned 3 inches (7.6cm) back and under the vertical trays approximately 2 ft. (0.6m) up. In order to provide uniform amounts of heat, purified (copy unclear) natural propane gas was better than industrial-use propane gas.

Table 8. Material Data Form[a)]

600-Volt Control Cable-EPR Insulation and Neoprene or CSP Jacket.

1) Physical and electrical characteristics of EP dielectric when tested in accordance with IPCEA S-19-81 Part 6, Section as noted and IPCEL S-68-516, Section 3.6.1. The vulcanized insulation shall meet the following		Required
a. Physical requirements before aging (Section 6.4)		
(1) Tensile strength, min	lb/in^2 (g/cm^2)	700 (4.88×10^4)
(2) Elongation at rupture, min	%	250
b. Physical requirements after aging (Section 6.4, except at 150°C)		
After 168 hours in air oven at 150°C		
(1) Tensile strength, min, % of unaged value		75
(2) Elongation at rupture, min, % of unaged value		75
c. Ozone resistance (Section 6.8)		
3 hours at 0.025% concentration		No cracks
d. Accelerated water absorption (Section 6.9)		
(1) Electrical method EM-60, water maintained at 75°C		
(a) Dielectric constant after 24 hours immersion, max 60 Hz		4.0

(b) Increase in capacitance between 1 to 14 days, max		3.5
(c) Increase in capacitance between 7 to 14 days, max	%	1.5
(d) Stability factor after 14 days, max	%	1.0
(e) Alternate to stability factor, 1 to 14 days, max	%	0.5
(2) Gravimetric method		
Water absorption, max	lb/in^2 (mg/cm^2)	2.5×10^{-5} (1.6)
e. Insulation resistance constant (K) (Section 6.23)		
At 60°F (15.6°C) per 1,000 ft (300 m)		20,000
2) Physical and electrical characteristics when samples are tested in accordance with IPCEA S-19-81, Part 6, Section as noted below and IPCEA S-68-516, Sections 4.4.3 and 4.4.9. The vulcanized thermoset jacket shall meet the following :		Neoprene
a. Physical requirements before aging (Section 6.4.5)		
(1) Tensile strength, min	lb/in^2 (kg/cm^2)	1,800 (12.57×10^4)
(2) Tensile stress at 200% elongation, min	lb/in^2 (kg/cm^2)	500 (34.88×10^3)
(3) Elongation at rupture, min	%	300
(4) Set, max	%	20

b. Physical requirements after aging (Section 6.4.5 applies as above.)		
(1) After 168 hours in air oven test at 100°C		
(a) Tensile strength, min, % of unaged value		50
(b) Elongation at rupture, min, % of unaged value		50
(2) Oil immersion, 18 hours at 121°C, ASTH No. 2 oil		
(a) Tensile strength, min, % of unaged value		60
(b) Elongation at rupture, min, % of unaged value		60
c. Physical requirements before aging (Sect. 6.4.5)		
(1) Tensile strength, min	lb/in^2 (g/cm^2)	1,800 (12.57×10^4)
(2) Tensile stress at 200% elongation, min	lb/in^2 (g/cm^2)	500 (3.49×10^4)
(3) Elongation at rupture, min	%	300
(4) Set, max	%	30
d. Physical requirements after aging (Section 6.4.5 applies as above.)		
(1) After 168 hours in air oven test at 212°F (100°C)		
(a) Tensile strength, min, % of unaged value	%	85
(b) Elongation at rupture, min, % of unaged value	%	65
(2) Oil immersion, 18 hours at 250°F (121°C), ASTM No. 2 oil		
(a) Tensile strength, min, % of unaged value	%	60

(b) Elongation of rupture, min, % of unaged value	60
e. Cold bends with mandrel diameter to be 8 by OD of single conductor. (Section 6.4.13.8 except -40°C) Immediately after 24 hours at -40°C	Not required
f. Discharge-resisting jackets (performed on single conductor, nonshielded, 2 kV to 5 kV phase-to-phase) (Sections 4.13.11 and 6.20.1). Specific resistivity, min, M	Not required
g. Ozone resistance (Section 6.8.3.1)	
After 3-hour exposure, 0.015% concentration	No cracks

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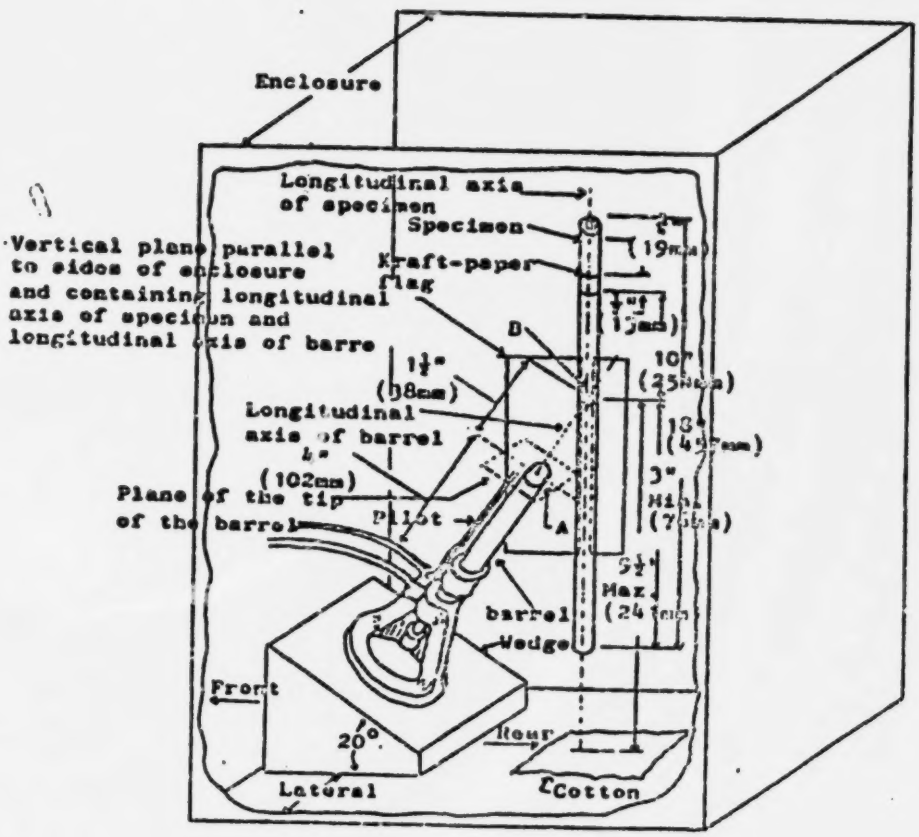
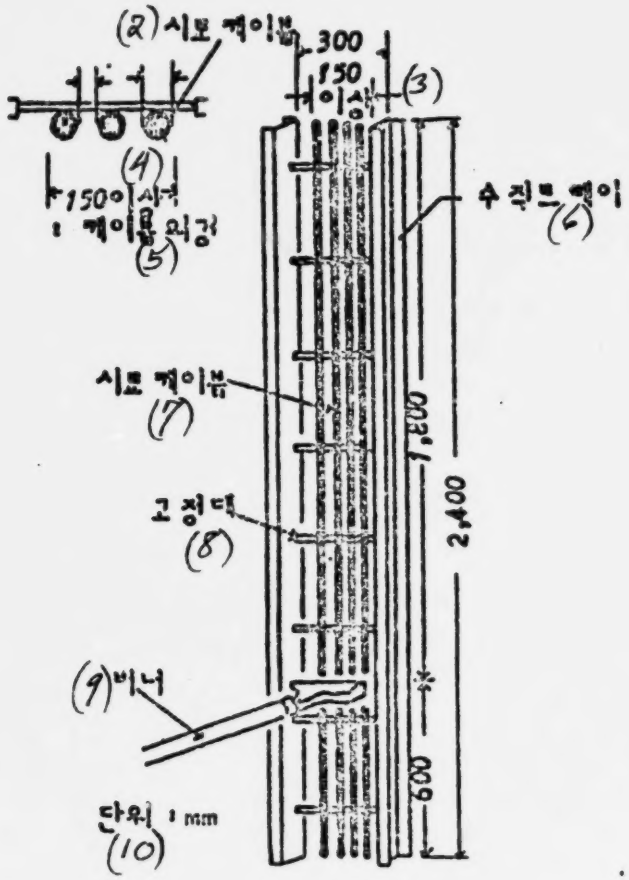


Fig. 3 Vertical Flame Test Equipment and Diagram



(1) 그림 4. 수직트레이 연소시험 장치에서 케이블의 배열 방법 [18]

1. Fig. 4 Arrangement Method of Cables in Vertical Tray Combustion Test Equipment (18) (number unclear) 2. Test Sample Cable 3. Or More 4. Or More 5. Cable Outer Diameter 6. Vertical Tray 7. Test Sample Cable 8. Fastener 9. Burner 10. Unit

(6) As far as the temperature of the flames is concerned, it had to be 1,400-1,500 degrees F. (760-815.5 deg. C) when measured by a thermocouple positioned close to the flame (approximately 1/8th inch of space) so that the flames did not burn the surface of the test materials. 32

(7) In a dynamic state, as far as the air-gas mixture is concerned, it has to be as follows.

(a) If propane gas is used, in the supply tube of the venturi mixer, as far as the gas pressure is concerned, by a water barometer, it is -1.0 inch $\pm$ 0.12 (-2.6cm $\pm$ 0.3cm); and, as concerns the air pressure, by the water barometer, it is 1.7 inch $\pm$ 0.2 (4.3cm $\pm$ 0.5cm) (See Fig. 5).

(b) If commercial gas is used, in the supply tube of the venturi mixer, as far as the gas pressure is concerned, by a water barometer, it is -0.4 inch $\pm$0.04 (-1.0cm $\pm$ 0.1); and, in the case of the air pressure, by a water barometer, it is 2.2 inches $\pm$ 0.2 (5.6cm $\pm$ 0.5) (See Fig. 5). 34

(c) As concerns pressures of this type, they can be changed to achieve the specified temperatures of the test samples with approximately a 15 inch (38.1cm) flame arc.

(8) While setting light to the burner, all monitoring circuits at the same time go into operation. As far as the burners are concerned, they burn for a 20 minute period, and this establishes the following conditions.

(a) Record the time required up to the time when the circuit cannot function. (b) The time the flame continues after the gas burner is lit. (c) Char length above the contact point. (d) Flame temperature at the point of contact. (e) The distance along which the insulation is damaged.

(9) These same parameters, through the process of the testing, are flame tested 3 times, and there is a need to establish a definite level of flame retardancy in the structure of the cable. Tests are also carried out according to IEEE 383 as concerns test samples aged due to thermal aging.

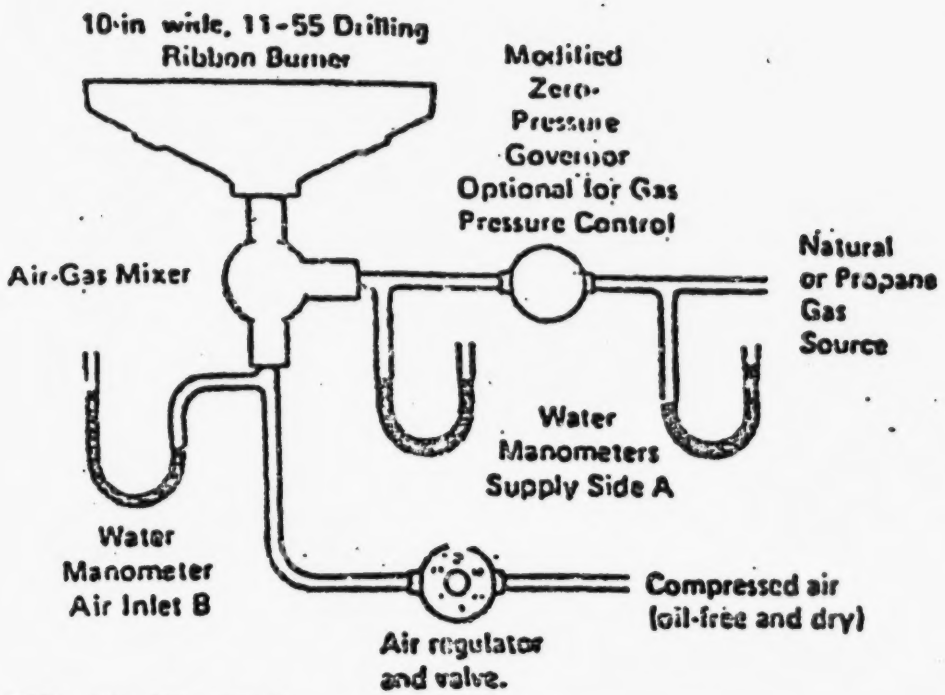

10-in wide, 11-55 Drilling Ribbon Burner
Modified Zero-Pressure Governor Optional for Gas Pressure Control
Air-Gas Mixer
Natural or Propane Gas Source
Water Manometers Supply Side A
Water Manometer Air Inlet B
Compressed air (oil-free and dry)
Air regulator and valve.

Fig.5. IEEE Std 388-1974 [3]

NOTE: All pressures measured under dynamic conditions.

(10) After the flame source is interrupted or extinguished, it is observed whether or not there is cable flame propagation. As far as cables which spread the flames to the end of the tray are concerned (copy unclear), they do not pass the test. When the flame source is eliminated, cable which extinguishes itself passes the test.

3) Chemical Tests

Chemical tests on insulation materials and coverings can be generally seen as divided into three types of tests; that is, (a) tests on corrosion effects, (b) oxygen index tests, and (c) oxygen gas generation tests.

a) Tests on Corrosion Effects

Generally, as far as corrosion tests are concerned, they can be divided into three types - noncontact type tests, contact corrosion with heat tests, and cyclical corrosion tests. By the use of any one type of method, all knowledge concerning corrosion of substances cannot be obtained, but, making use of all three types of methods is good guidance in testing practice. As far as corrosion is concerned, as the result of the chemical attraction between the constituent materials of electrical wires and copper, if there are changes in the their material construction, since the electrical characteristics will also be degraded, this will lead to electrical current leakage, and the circuits will be made unserviceable. As concerns corrosion, it is also greatly dependent on environmental conditions; that is, in the case of some types of material construction, in dry heat, copper metal does not have an influence, but, in humid heat or the opposite condition, copper can be corroded. Because this is so, in different environments, the obtaining of corrosion effects on materials and the understanding of them is important. However, in the case of the cables used in atomic power generating stations, as far as the corrosion effects on the insulation materials and covering materials of cables is concerned, according to ASTM D 2671, it can be determined according to the copper-mirror corrosion method. 35

As far as test samples are concerned, the front of the samples are treated with 50±2% humidity at 23±1deg.C temperatures for a period of 4 hours. At the elevated temperature, the test samples are taken out and the corrosion of materials is measured. As concerns the copper mirror, it is set up to condense the copper causing corrosion. If a material gets through approximately 16 hours, its corrosion

characteristics are classified as adequate to be designated as non-corrosive.

(1) Test samples of insulation materials with a width of 1/4 inch (0.64cm), a length of 1 inch (2.54cm), and a thickness of 17 mils (1.2mm) were made use of in the testing tube, and, in a position 6-7 inches (150-180mm) above the floor of the test tube, together with a thermometer, the copper glass mirror, with a width of 0.25 inches and a length of 1 inch, is covered over by copper wire binding it to a fire in the coke. Moreover, after this, the test tube is sealed with coke wrapped in aluminum foil.

(2) Into a 345 degree F. (175deg.C) oil bath, the bottom section of the test tube was submerged 2 inches (5.1cm) and made to react for 16 hours. 36

(3) The temperature of the portion containing the copper mirror inside the test tube was maintained at 60 deg. C or below.

(4) After being cooled, the mirror was put onto white paper under red light and investigated, and whether or not the copper had been eliminated from the mirror was the evidence left of corrosion. As far as the copper on the 0.06 inch (2mm) bottom section of the mirror is concerned, it had been eliminated. The reason for this was that corrosion had been possible due to the dipping. Other cases of the decolorization of the copper film or the reduction of its thickness were not thought of as corrosion.

(5) Places where the copper had been eliminated and light could get through were evaluated as corroded sections. As far as the mirror was concerned, it permitted the transmission of 5000 Angstrom normal light at 10$\pm$5%, and was vacuum coated with a uniform thickness of copper. The areas of the portions of the total surface area of the copper mirror on which the copper had been eliminated were expressed as %.

b) Oxygen Index Tests

(1) Before Aging

(a) An exception to the carrying out of three tests on each of the various forms of material was made in accordance with ASTMD 2863.

(b) As far as the tests are concerned, they were carried out with compound test materials taken from various batches of ethylene-propylene and neoprene or CSP compounds.

(2) After Aging

Making an exception for the 7 hour aging of the test samples in an air oven at 302 degrees F. (150 deg. C), the testing process and the parameters were the same as those before the aging.

c) Oxygen Gas Production Tests 37

As far as the HCl which was produced from burning cable insulation and covering materials is concerned, it was measured as follows.

(1) As concerns the test equipment, it was as shown in Fig. 6, and, as far as the fused quartz tube and the porcelain boat are concerned, they were cleansed by flames from organic matter and contaminants (copy unclear).

(2) Under 6 inches (15.2cm) of water pressure commercial gas was supplied by Fisher-Meker-type burner, and, as far as the adjustment orifice is concerned, it was completely opened.

(3) Before introducing the test materials, the tube was heated for 5 minutes, and this caused the appearance of a reddish color.

(4) 1mg of test material was put into the porcelain boat.

(5) Through the rubber stopper, the Mine Safety Appliance (MSA) detector tube, Part No. 91636 (with the pulling portion broken) was introduced. The arrow direction on the other detector tube was directed toward the sampling pump area.

(6) The porcelain that the test samples were loaded into was rearranged with a long electric wire, and was put into the center of the burner flame, so that, when the porcelain came into the center of the flame, the dial or stop switch was made to operate.

(7) The other end of the fused quartz tube was immediately blocked as the metering orifice, and, 15 seconds afterward, the MSA pump made one back-and-forth movement.

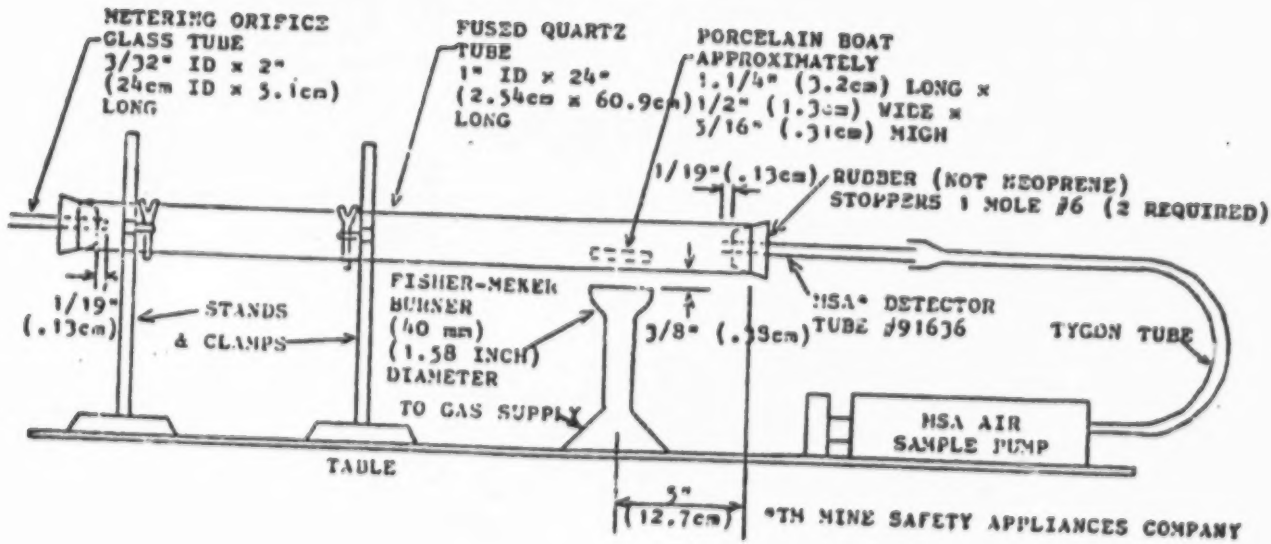


Fig. 6 Oxygen Gas Generating Equipment (20) (Copy Unclear)

(8) 1 minute after the back-and-forth movement of the pump, the detector tube was read. If the recorded reading went full scale on the graduations, again, the back-and-forth movement was set in motion 2/1 times, the graduated scale read, and, if it was still not satisfactory, tube calibration was done by the exterior insertion of a scale. 39

(9) From each batch of ethylene-propylene and neoprene or CSP compounds, 5 tests were done and averaged to determine a measurement.

(10) As far as the oxygen gas generation is concerned, it was guided by the formula below.

parts per million per milligram (p/m/mg)

$$= \frac{\text{detector tube reading (p/m)}}{\text{pump stroke}}$$

4) DBE and LOCA Tests (21) (Copy Unclear)

As far as these tests are concerned, they can be seen as roughly divided into 4 types; that is, (a) heat aging, (b) radiation exposure, (c) hypothetical LOCA tests, and (d) after LOCA hypothetical testing. As concerns the 7/C-14(AWG) test cable samples being handled and the limits involved, under the conditions hypothesized for the occurrence of LOCA, whether operation is possible or not becomes apparent.

a) Heat Aging Tests

As far as the handled or finished 7/C-14(AWG) test cable samples are concerned, their thermal aging process was the same as that described in item b. 1) above for normal thermal aging test conditions.

b) Radiation Exposure Tests

As far as aging test samples are concerned, at the time of LOCA, the amount of radiation exposure assumed is 1.1×10^8 rads (copy

unclear) which is the sum of a postulated amount of radiation exposure of 1.0×10^8 rads plus an amount of 40 years accumulated radiation exposure of 0.1×10^8 rads.

c) Hypothetical LOCA Tests

As far as unaged, radiation exposed test samples and thermally aged, radiation exposed test samples are concerned, both of them, under conditions of exposure to pressures, temperatures, and chemical sprays hypothesized for the time of LOCA incidents, and, at specified voltages and loads, are tested for their ability to operate in specially constructed pressure containers. As concerns these chambers, their temperatures and steam contents can be changed, and their chemical sprays can be recirculated. Voltage loads can be connected to the test samples, and they are planned so as to have equipment for monitoring. As far as the test samples which are set up inside the pressure vessels are concerned, they operate at regular electrical levels under normal operating conditions, and they are loaded with regularly specified current flows. As concerns the cables, within clearly stated electrical parameters, even though exposed to extreme environmental conditions, electrical operation took place. As far as the hypothetical LOCA testing plan is concerned, it is as presented in Table 8.

d) Hypothetical Post-LOCA Testing

At the same time that the hypothetical LOCA testing is finished, the test samples are spread out properly, wound again radially on the metal axial core to a thickness about 40 times the diameter of the cable, and soaked in tap water at room temperature. While immersed in the tap water, the test samples were given 5 minutes of voltage resistance testing with electrical potentials of 80 volts/mil (80 volts/0.025mm) ac or 240 volts/mil (240 volts/0.025mm) dc.

In the cases of control cable, instrument cable, or 600 volt power cable also, since the testing methods and required items were similar to those described above, in order to save time, it is hoped that the reader will consult references 19-22 for detailed materials.

3. Test Results and Considerations

This year, among the nuclear power generating station type cable normality tests, flame tests, chemical tests, DBE and LOCA tests, we dealt with the design and construction of the test equipment related to flame tests and did flame tests. Also, we measured some of the physical characteristics of irradiated cable.

a. Physical Characteristics of Cable

Three types of power cable samples, KERITE 1979 #4/0 AWG 600V HTK-FR #4974, 19/C 14 AWG ROCKBESTOS 600V Firewall III XHHW NEC TYPE TC (UL), 5/C 14 AWG ROCKBESTOS Firewall III, through the utilization of 600V Cobalt 60 gamma rays, were irradiated with 150 Mrad at the rate of 1.1×10^6 rads/hr. Among the irradiated cables, in the cases of 19/C 14 AWG and 5/C 14 AWG, the irradiation damage which occurred got so bad that, with only a little bending, it broke. However, as far as #4/0 AWG 600V HTK-FR # 4974 is concerned, although it was considerably damaged by the radiation, when deformed, the cable covering did not break, and continuity was maintained.

In an effort to relate the physical characteristics of cables to their gel%, 3 types of cables which had been irradiated with 150 Mrads were tested in comparison with non-irradiated cables. The results of testing irradiated cables and non-irradiated cables with various solvents are found in Table 9. As far as the solvents used on this occasion are concerned, petroleum ether, n-hexane and xylene, all of which are able to dissolve polyethylene and polypropylene components, were utilized. As comes out in Table 9, although the cable test samples were put in a solvent of petroleum ether and refluxed for 90 hours, #4/0 AWG 600V HTK-FR #4974 swelled up in a striking manner. 42
As far as the test samples are concerned, they were dried, and they were weighed so as to determine their gel%. However, there were no changes in the weight, so this was no help. Because of this, the cable test samples were again put into n-hexane and refluxed for 90 hours, after which they were dried, and, when they were weighed, there was a 0.2-4.6% level reduction in weight. Along with this, after the

test samples above were once again put into Xylene solvent, refluxed for 90 hours and dried off, a weighing of them showed a 5.9-10.2% level reduction in weight. In the case of #4/0 AWG 600V HTK-FR #4974 cable, in a comparison of cable which had not been irradiated with cable samples which had been irradiated with 150 Mrad, although it was thought that there would be an approximately 6% polymer reaction, in 19/C 14 AWG and 5/C 14 AWG cables, there was not more than a 1% difference between irradiated test samples and non-irradiated test samples, so it was thought that the polymer reaction and the breakdown reaction occured to the same degree and that there were various factors involved in them. Not only this

(1) 표 9. 케이블에 대한 용성

(3) (2)시 료 / 용 매	600V HTK FR#4974		5/C 14 AWG		19/C 14 AWG	
	미조사 (4)	150 Mrad	미조사 (4)	150 Mrad	미조사 (4)	150 Mrad
petro. ether	-	97.58	-	100.49	-	100.56
n-hexane	89.22	95.36	98.01	99.80	97.54	99.87
xylene	83.67	89.84	98.67	97.59	95.66	94.12

(5) 참조 : 표의 수치는 각용매에서 90시간 환류시키고난 후 남은 시료량의 %값.

1. Table 9. Material Properties of Cables 2. Test Materials 3. Solvent 4. Non-Irradiated 5. Reference: The numerical values in the Table are % values for the amounts of test materials remaining after 90 hours of refluxing in the various solvents.

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16. Abstract

The polymers PE, EPR, PVC, Neoprene, CSP, CLPE, EP and other similar substances are frequently being used as insulation and covering materials for cables used in nuclear generating stations. Giving consideration to the required information for these cables for flame retardancy and environmental resistance tests as well as to the experimental methods and cable specifications, through the cable normal test, flame test, chemical tests, design basis event and loss of coolant accident tests plus basic material collected concerning the spark tests and actual experience, standards were fixed through these contributions and technology was accumulated.

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